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DISTILLATION PRESSURE CONTROL TROUBLESHOOTING – THE HIDDEN PITTFALLS OF OVERDESIGN

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Abstract

The operating pressure of a distillation column is one of the main handles with which to control and optimise separation as it affects most other parameters as well as the overall stability of the column. It is therefore one of the most important parameters to control. Controlling a distillation column, designed to be operated under a vacuum, at the intended operating pressure can prove to be much more difficult than for positive pressure columns especially during the initial start-up of the column. Determining the cause of pressure instability can be a daunting task as the column will most likely be under turndown conditions, the inventory might differ from the intended composition, the control loops will be in manual or not tuned yet or the cause might even be from an equipment design perspective.

During the initial start-up of a vacuum operated distillation column several problems were encountered that prohibited the column from being operated at its intended pressure. This caused severe instabilities in the column and also affected the downstream sections of the plant. This paper focuses on these problems and the troubleshooting to determine the causes of the pressure instability.

During troubleshooting a number of key factors that contributed to the pressure instability were identified, with the main cause being the design and expected air ingress into the column. This influenced the design of several pieces of equipment in and around the column. A deviation from the design air ingress meant that several design parameters had to be re-evaluated in order to eventually reach the intended operating pressure. A conventional pressure control philosophy was implemented, but changes to this were required in order to achieve the necessary stability in the column. The improved control philosophy has several benefits, such as a reduced number of variables to be manipulated by the operator, smoother change over between the primary pressure controller and the setpoint high controller, as well as optimising the product losses to the vacuum system.

Keywords: distillation, pressure control, over design, condenser, air ingress

1. Background

The operating pressure of a distillation column is one of the key design parameters. It affects several other design parameters like operating temperatures and key component relative volatilities which ultimately determine the separation quality. Column operating pressure is therefore one of the most important parameters to control. Instability in the operating pressure will most likely not only affect the column performance, but also impact the downstream sections of a plant.

Conventional pressure control philosophies for all modes of operation are well documented in the literature[1]. These are sufficient in many cases, but for special circumstances the operation of the pressure control requires special attention. Assumptions influencing the selection and design of the pressure control philosophy might prove invalid during operation and this can have serious consequences on the operational stability of the column and consequently impact plant performance. Several problems were encountered during the initial start-up of a distillation column operated at vacuum conditions. These problems prevented the column from achieving its intended operating pressure. This paper addresses these problems as well as the troubleshooting process followed to establish the root cause and regain the ability to tightly control the pressure. An Internal overhead dimple plate condenser is used in the distillation column discussed. Treated condensate referred to as warm tempered water (WTW) is used as cooling medium in the condenser. The tempered water system (TW) was designed to deliver sufficient duty to the condenser of this column as it is the tallest and also operated at the highest temperature.

2. Case study: Problem definition

The pressure control philosophy was based on a conventional philosophy that can be found in literature[1]. See figure 1 for a diagram of the philosophy selected during the design phase. The column was designed to be operated under a vacuum and the pressure in the column is controlled by manipulating the WTW return flow rate (PIC-101A). In the event of overpressure due to inerts build up, the inerts flow rate to the vacuum system is increased by means of a setpoint high controller (PIC-101B). The operator also has the ability to set a minimum valve to vacuum opening by making use of the HIC (HIC-101).

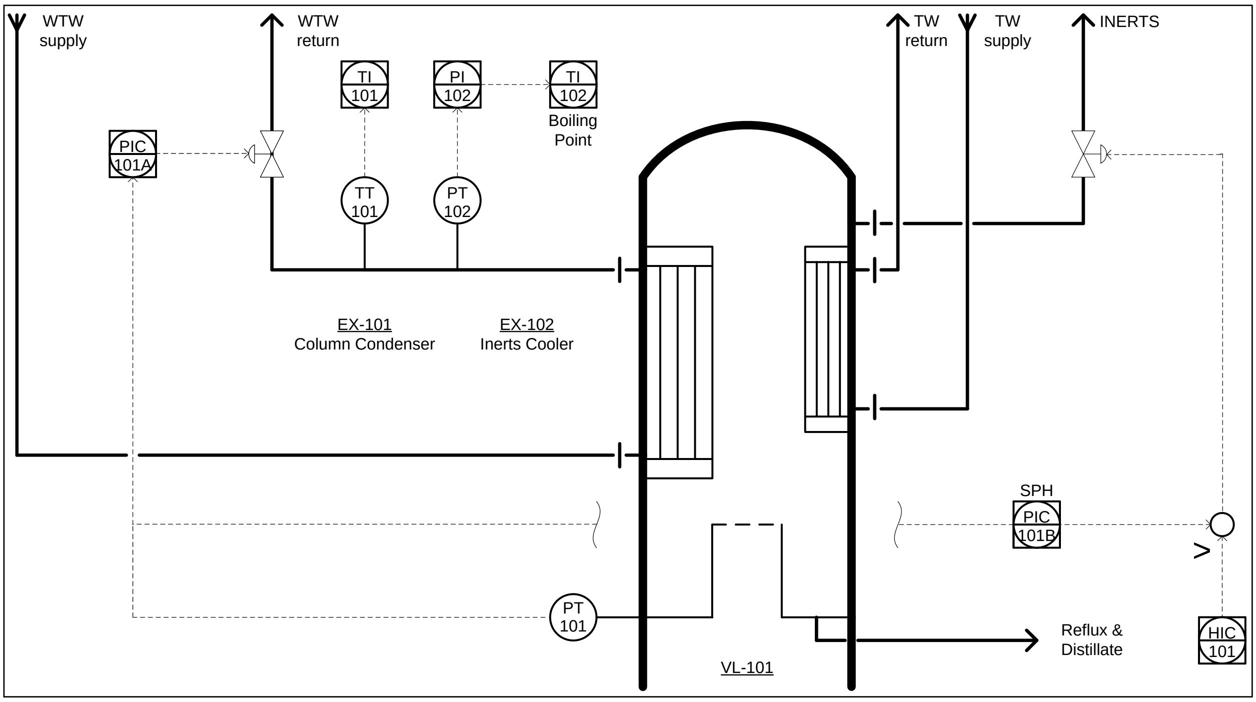

Figure 1. Design pressure control philosophy

A constraint on the WTW flow rate is the boiling point of the WTW return stream. The boiling point is calculated from the measured absolute pressure (PI-102) of the WTW return. The WTW return temperature (TI-101) is measured and several precautions have been set in place to prevent the WTW return from reaching its boiling point. These precautions are as follows:

- If the WTW return temperature reaches 110°C an alarm is activated. The operator should take preventative action at this stage.
- If the temperature reaches 85% of the boiling point a trip is initiated that fully opens the WTW return valve (PV-101A).
- If the temperature reaches 90% of the boiling point another trip is initiated to isolate the steam supply to the reboiler of the column.

During initial start-up of the vacuum operated topping and tailing distillation section, the intended operating pressures could not be attained. The WTW return temperature was constantly higher than the design return temperature and the high alarm was initiated at regular intervals. The operators took preventative action by manually increasing the WTW flow rate to lower the WTW return temperature. The effect was increased condensation in the condenser and hence a reduced operating pressure. The WTW valve opening was controlled manually to maintain the WTW return temperature below the high alarm. The pressure was allowed to stabilize and steadied at a value 40 kPaa lower than the design operating pressure. Although stable operation was achieved at this pressure, concerns were raised that the column might be hydraulically limited at design capacity.

3. Troubleshooting

3.1. Problem identification

During initial start-up of the plant the column was being operated at turndown conditions due to the reduced production rate of the upstream plant sections. The small WTW valve opening during initial operation suggested that the column (and the condenser) was only partially loaded. This was believed to be partly responsible for the lack of stable pressure control. Solution proposals were developed by a multi-disciplinary team including process engineers, a control specialist and key operations personnel.

3.2. Control philosophy changes

An improved pressure control philosophy was implemented and a diagram of this can be referred to figure 2. An added margin of safety was implemented to prevent the WTW return temperature from reaching the high alarm. This was done in the form of a TIC controller (TIC-101). The setpoint of the controller is calculated by subtracting a pre-defined margin from the calculated WTW return boiling point temperature (TI-102). This TIC controller would set a minimum WTW valve opening to ensure that the WTW return temperature does not reach the high alarm. The output parameter of the TIC controller is combined with that of the normal pressure controller (PIC-101A) in a high selector that sets the WTW valve opening.

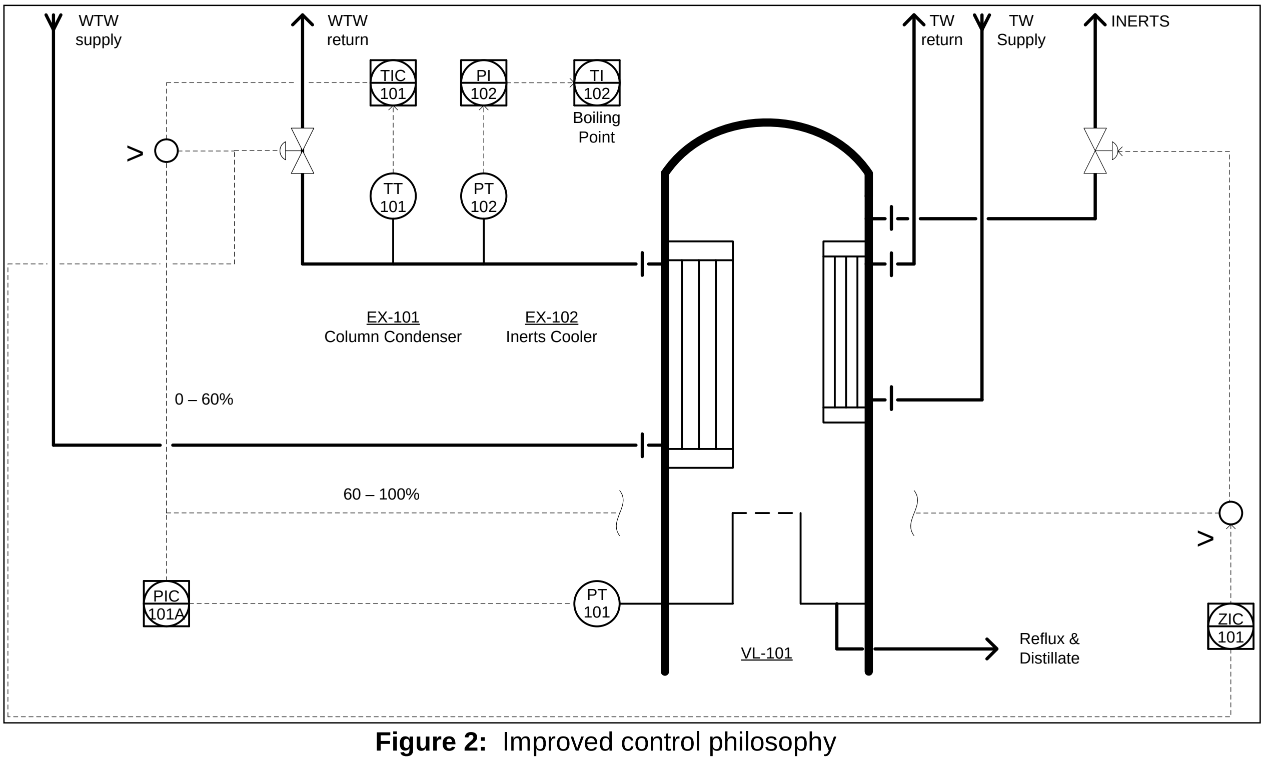

Figure 2: Improved control philosophy

Instead of the original setpoint high controller (PIC-101B) a new split range controller was implemented. The normal pressure controller (PIC-101A) will have 0 – 60% action on the WTW valve and 60 – 100% action on the valve to vacuum in an over pressure situation. This would give the benefit of a smoother change over of the pressure control from the WTW valve to the valve to vacuum. The operating pressure would also remain closer to the setpoint during this change over than it would in the case of the setpoint high controller of which the setpoint needs to be offset from the main column pressure controller to avoid interaction of the two individual control loops.

A valve position controller (ZIC-101) was implemented to manipulate the valve to vacuum opening in order to control the WTW valve at a certain valve opening. This removed the HIC (HIC-101) in the original pressure control design and eliminates the guess work required by the operator to find the optimum HIC setpoint. The setpoint for ZIC-101 is taken as the normal design WTW valve opening to prevent reducing the tempered water supply to other system users. Operating at this valve opening would ensure low WTW return temperatures. The output parameter from ZIC-101 is combined with that of the 60 – 100% action from PIC-101A in a high selector that sets the valve to vacuum opening.

The manual manipulation of several control loops as well as the lack of properly tuned automatic controllers were also believed to have contributed to the inability to reach the design operating pressures. After implementation of the above mentioned pressure control philosophy the PID parameters were also tuned to ensure that automatic control of the columns were possible. The original trip settings on the WTW return temperature were also changed in order to give extra flexibility to reach the design operating pressure of the columns. The changed settings are as follows:

- The TIC controller (TIC-101) will have a floating setpoint 30°C below the boiling point
- The high alarm will be floating 2.5°C above the TIC controller setpoint
- The trip to open the WTW valve 100% will be floating 25°C below the boiling point
- The trip to close the steam supply to the column will be floating 20°C below the boiling point

The improved pressure control philosophy as well as the changes to the trip settings improved the operational flexibility. This allowed for the light cut column to be controlled at its design operating pressure. The heavy cut column was however still operating at a deeper vacuum than intended, with the new TIC controller (TIC-101) setting the WTW valve opening instead of the normal pressure controller (PIC-101A). This meant that the pressure was not being controlled, but rather the WTW return temperature.

By now the section was operating at flow rates close to that of the minimum design case and the effect of the turndown conditions on the WTW return temperature was becoming less evident. Although the pressure was not controlled at the setpoint it was stable. It was questioned as to why not reduce the pressure setpoint to the current pressure and allow the pressure controller to manipulate the WTW return flow rate instead of the TIC controller (TIC-101) manipulating it. Although the flow rates have increased from the initial start-up the effect of the reduced pressure might limit the column hydraulically when reaching the design flow rates. It was therefore necessary to try and reach the design operating pressure.

3.3. Root cause of pressure control problems

Further investigation into what might be the cause of the high WTW return temperatures lead to the conclusion that it was a lack of air ingress. The original design catered for an air ingress rate of 31 kg/hr based on the total amount of gaskets in the system and their expected leakage rates. The air ingress designed for comprises of air leakage into the column as well as inerts dissolved in the feed stream to the column. This would lead to an increased condenser area required in order to achieve the necessary condensation with the non-condensable components present. Vacuum testing of the column during commissioning indicated that the air leakage into the column is only about 0.28 kg/hr. The amount of dissolved inerts in the column feed is also believed to be negligible as most will be removed upstream in the light cut column. The total air ingress would thus be much less than designed for and hence the condenser area would therefore be overdesigned. Solving this problem would be to cut back on the WTW return flow rate, but due to the boiling point protection system on the tempered water system this could not be done unreservedly.

To compensate for the lack of air ingress nitrogen was added to the column via an installed line. A rotameter measured the amount added and it was decided to start off with 1.5 Nm3/hr. The aim of the nitrogen addition was to blanket a part of the condenser to reduce the area available for condensation. This would lead to an increased WTW return flow rate and hence a lower WTW return temperature. The control configuration was designed to remove inerts from the column to the vacuum system and it was believed that a state of equilibrium would be reached when enough of the condenser area was blanketed and the WTW valve opening had reached the setpoint of the ZIC controller (ZIC-101). The ZIC controller would then open to remove the nitrogen to keep the WTW valve opening at the design value which is also used for the setpoint of the ZIC controller.

This did however not work as planned and the column was operating in constant oscillations of ±10 kPa around the desired pressure setpoint causing the level of the reflux compartment and sump as well as the temperatures in the column to oscillate. Control engineers helped to fine tune the parameters of the PID controller of the normal pressure controller (PIC-101A), but the oscillations continued. The final product flow is on level control from the reflux compartment and the constant fluctuations in the flow were starting to affect the downstream plant sections.The exact cause of why the nitrogen addition did not work is not known, but the most likely cause is due to the delicate balance that is required between the control valve characteristics and the nitrogen addition rate. The line sizes and the valve characteristics of the WTW valve and the valve to vacuum differ significantly and the parameters of the normal pressure controller (PIC-101) will not be suitable for optimal pressure control with both valves.

The nitrogen did have the desired effect of blanketing the condenser and an increase in the WTW valve opening was noticed. The pressure increased to the point where the pressure control was changed from the WTW valve to the valve to vacuum. This caused a sudden drop in pressure indicating most of the nitrogen was removed from the column overheads and exposing all of the condenser area once again. The pressure dropped and the TIC controller (TIC-101) took action to prevent the WTW valve from closing too much. This started the entire process of blanketing the condenser with nitrogen all over again. It was not known if the nitrogen amount added was too small or too much, because a too large flow would blanket the condenser too fast and not give the controllers enough time to react while a too small flow rate would not be able to keep sufficient blanketing when the valve to vacuum opens.

3.4. Final solution

The engineering consultant responsible for the design gave recommendations to reduce the margins between the alarm and trip settings on the WTW return temperature. The idea behind this was to allow the WTW valve to cut back in order to reach the design operating pressure. Upon investigation of the vapour pressure vs. temperature curve of the final product, it was evident that the originally recommended margins from the engineering contractor would not be sufficient to reach the design operating pressure.

It was however decided that this was the correct approach in solving the problem and reaching the design operating pressure. A new proposal was set up taking into account the temperature of the final product at the design operating pressure and combining this with a temperature approach in the condenser. The response of the WTW return temperature with changes in the WTW valve opening was investigated as well as the effectiveness of the TIC controller (TIC-101). With all of this in consideration the alarm and trip setting were changed to the following:

- TIC-101 will have a floating setpoint 12.5°C below the boiling point
- The high alarm will be floating 11°C below the boiling point
- The trip to open the WTW valve 100% will be floating 10°C below the boiling point
- The trip to close the steam supply to column will be floating 7.5°C below the boiling point

A 7.5°C margin between the last safety measure and the normal operating boiling point of the WTW return stream was deemed sufficient as the temperature of the final product is lower than that at the normal operating pressure. These alarm and trip settings gave the necessary flexibility to the normal pressure controller (PIC-101A) to cut back on the WTW flow rate to reach the design operating pressure.

4. Conclusion

The estimated air ingress into the column influenced the design of the condenser, in particular the condenser surface area. A lower than design air ingress during operation meant that a lower WTW flow rate was required to control the pressure at the design operating pressure and this resulted in a higher WTW return temperature.

Safety measures implemented to prevent the WTW return from reaching its boiling point prevented the column from being operated at its intended operating pressure. Efforts to substitute the lack of air ingress with nitrogen proved impossible and caused uncontrollable oscillations that affected not only this column but also downstream sections of the plant.

The pressure control philosophy of the column was changed. It ensures smoother change over between normal and over pressure control situations and reduces the number of variables to be manipulated by the operator. The new philosophy also manipulates the valve to vacuum opening to control the WTW valve opening as close to the design valve opening as possible. This ensures that the WTW return temperature does not reach the implemented safety measures.

The original margins for the temperature trip safety measures did not take into account start-up conditions or a lack of air ingress. Careful consideration for the temperatures expected at the design operating pressure as well as the integrity of the equipment allowed for new margins to be implemented to enable the controller adequate flexibility to reach the design operating pressure of the column.

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References

1. H.Z. Kister, Distillation Operation, McGraw Hill (1989)